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Recent Developments in the Economics of Science and Innovation

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Building the economics of knowledge: A roadmap

The analysis of the causes and consequences of the increase of the general efficiency of labor and the associated changes in production, consumption, and distribution brought about by the introduction of new technologies in economic systems is a field of economic investigation of growing interest and widening activity both in research and teaching.

This field has evolved over time, partly in response to the changing focus of economic analysis. This area of investigation was identified as "the economics of technical progress" for a large part of the 20th century. In the 1960s and 1970s, it was referred to as "the economics of technological change," and through the 1980s and 1990s it became known as "the economics of innovation." Since then a new shift occurred to bring to the attention of scholars "the economics of knowledge" as a crucial crossing between the economics of science and the innovation.

The scholarship that we have included in this edited volume marks the new emphasis of the inquiry into the intrinsic characteristics of knowledge as an economic activity. The identification of the crucial role of knowledge as an economic activity in grasping the causes and consequences of technological change has pushed the field of economics to investigate in detail the economic processes that shape the generation, dissemination, and exploitation of technological knowledge.

The economic analysis of the causes and consequences of the increase in the general efficiency of economic activities—and the parallel changes in production, consumption, distribution, and technology—is a challenging area of investigation. The standard (classical or neoclassical) economic framework of analysis is unable to accommodate the endogenous explication of the increase of efficiency.

This shift in denomination is the direct consequence of the changing attitude of economics from the initial attempt to consider technological change, and the attendant increase of efficiency, as emanating from exogenous events, to the awareness of the role for technological change for which standard tools of economics could analyze. Early on economics did investigate the consequences of the introduction of technological change, but the discipline had little to say about the causes of technological change. This phase of evolution coincides with "the economics of technical progress."

The discovery of the so-called residual, along with an appreciation of its size, pushed economics to investigate more deeply the characteristics of the new technologies in terms of factor intensity, elasticity of substitution, output elasticity, and technology diffusion. This phase of academic understanding coincides with "the economics of technological change."

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The growing understanding about the variety of technologies being introduced and their relevance in determining the continual reproduction of disequilibrium conditions pushed economics to explore the processes that accompany the introduction of technology and its diffusion, and to try to elaborate upon the incentives to innovate and to understand the distribution of adoption of the new innovation. This phase coincides with "the economics of innovation" and the retrieval of the Schumpeterian legacy with its emphasis on the dynamic role of entrepreneurship.

The last step leading to "the economics of knowledge" has been marked by the understanding of knowledge externalities that stems from two fundamental and key characteristics of knowledge: its non-exhaustibility that makes it possible to use it again and again, and its limited appropriability that enables third parties to take advantage. Here the contributions of Zvi Griliches (1979 and 1992) and Paul Romer (1994) implemented the arrovian path breaking analysis on the central role of knowledge as a special kind of economic good (Arrow, 1969; Griliches. The expansion of economics into the analysis of the processes that lead to the generation of new scientific knowledge and its applications to economic activities marks the identification of the economics of science as a distinct area of research and teaching (Arrow, 1969).

The appreciation of cumulability, next to non-exhaustibility and limited appropriability, as the third crucial characteristic of knowledge, marks the establishment of "the economics of knowledge" as an area of specialization and professional competence in academics where it is increasingly taught not only in departments of economics but also throughout business schools.

This academic acknowledgment of "the economics of knowledge" arguably has profound implications for both economic analysis and social action in terms of public policy and firms' strategy. We articulate briefly these two distinct, and yet inter-related points. With respect to the scope of economic analysis, the acknowledgement of the implications of the combination of non-exhaustibility, limited appropriability, and indivisibility, both diachronic (cumulability) and synchronic (complementarity), makes it possible to identify the culprit of the increase of efficiency: knowledge is essential for the efficiency of an economic system, and it is essential to articulate a coherent explanation for increases in total factor productivity.

The increase of efficiency of an economic system takes place as a result of the possibility to use knowledge again and again not only as an intermediary input for the production of all other goods, but also to generate new knowledge. The generation of new knowledge, in fact, impinges necessarily upon the use of existing knowledge as an intermediary input.

Knowledge is not only a crucial input into the production of all the other goods, but also the output of dedicated activities that imply the intentional use of economic resources. The discovery of the twin identity of knowledge as both an output and an input, not only in the production of all the other goods but also of new knowledge, opens new fields of investigation and provides a consistent framework of analysis to account for increases in total factor productivity.

The new advances of "the economics of knowledge" make it possible to identify the limitations of the key assumption of the new growth theory, according to which knowledge externalities are automatically available to all agents in all conditions at no cost, became quickly evident. Technological knowledge does not spill freely like manna from heaven. Relevant search and absorption costs are necessary to acquire and use it (Antonelli, 2011) .

The characteristics of the system into which firms are located play a critical role in the effective dissemination of technological knowledge. The structure of the system in terms of industrial composition, the types of relations among firms, the features of intermediary markets, and the

availability of research enters both publicly and privately. Technological knowledge in the business sector plays a central role in assessing the actual availability and the cost of secondary use of existing knowledge. At the same time, it becomes evident that existing knowledge is an essential input into the generation of new knowledge. No new knowledge can be generated without the use of existing knowledge. The new growth theory framework requires substantial implementation. The analysis of the conditions that make existing knowledge available is a new building block within economic analysis (Weitzman, 1996).

Understanding the implications of knowledge as a peculiar kind of economic activity makes it possible to appreciate the limits of the standard analysis of markets and organizations as well as the need to explore the institutional context into which the division of labor and the exchanges that are necessary for the generation and the use of technological knowledge to take place (Antonelli, 2008).

Knowledge is characterized not only limited appropriability and divisibility, and non-exhaustibility, and the ensuing twin identity of both an output and an input, but also by relevant tacitness and high levels of risks. Because of knowledge tacitness, personal interactions are necessary to implement the division of labor and the related exchanges. Because of limited appropriability, standard property rules work poorly. Because of the crucial role of knowledge as an input into the generation of new knowledge, its timely dissemination and access are necessary.

The conditions for knowledge generation and knowledge exploitation are intrinsically in conflict. The limitations stemming from exclusive intellectual property rights to the dissemination and use of new knowledge have direct negative consequences on the efficiency of the generation of new technological knowledge. Redundant duplications of efforts reduce efficiency, and in some cases knowledge rationing caused by exclusive intellectual property rights may actually block the generation of new knowledge (March, 1991).

Under these conditions, the standard rules that make possible the working of markets and hierarchies for ordinary goods only apply to a limited extent. Markets and hierarchies need to be integrated by a strong institutional context that impinges upon different combinations among markets and hierarchies. Two dimensions are relevant for this analysis. The appreciation of the distinction between interactions and transactions and the identification and analysis of the variety of hybrid forms that provide the coordination that is necessary to benefit from the division of labor. As a matter of fact, coordination can either be *ex ante* or *ex post*. It can be obtained by means of managerial action *ex ante*, or by means of selective inclusion and exclusion, *ex post*. Pure interactions are organized by strong hierarchies. Pure impersonal transactions take place in perfect, impersonal, spot markets (Antonelli, 2011).

Between the two extremes, it is possible to gauge a variety of hybrid forms based upon the mix between transactions and interactions that are placed in a continuum between pure transactions and pure interactions. The overlap between interactions and transactions identifies an interesting area of complementarity where the two forms of organizing the division of labor complement each other. Here the type of coordination, whether *ex ante* or *ex post* plays a central analytical role. When interactions prevail, coordination is typically *ex ante*. When transactions prevail coordination takes place *ex post*.

Moving along the continuum, we can identify interactions-cum-transactions. These hybrid forms take place when transactions among partners take place in a context that is complemented by weak hierarchies. Interactions-cum-transaction are typically found within centered networks and especially structured platforms. In these hybrid forms, the coordination that is necessary to achieve

and integrate an efficient division of labor is defined *ex ante* and implemented by managers and hierarchical control.

Transactions-cum-interaction are typically found when transactions are reinforced by interactions such as in the case of long-term contracts and open contracts: transactions are no longer impersonal and no longer take place in spot markets. Partners in trade are personally identified and transactions are repeated over time. Here, coordination is however left to the market place and the ensuing competitive forces: coordination is achieved *ex post* also by means of selection and exclusion. Partners who are no longer able to meet the requested levels of performances are sanctioned with failure and exit. According to this analysis, venture capitalism can be considered a new case of hybrid form based upon interactions-cum-transactions.

Hybrid forms of governance are a key component of the broader set of rules, procedures, modes and protocols that enable the generation and the use of knowledge in an economic system including intellectual property rights and universities.

The working of knowledge governance mechanisms, at each point in time, within each economic system, can be seen as the spontaneous result of a systemic process of polycentric governance where the interaction between a myriad of actors is able to implement the emergence of structured and viable modes of coordination that are able to complement or substitute the imperfect allocation of property rights. Knowledge governance mechanisms change across time as the architecture of its elements is the object of different forces that act in diverse relations and reflect the changing weights within the system.

Economic history documents the emergence and implementation of different forms of knowledge governance. These different knowledge governance mechanisms can be considered alternative institutional solutions that have emerged through historic time by means of recursive processes of interactions and structural changes to better organize the complexity of knowledge interactions and support the creation and exploitation of knowledge externalities according to the changing knowledge infrastructure of the system (Ostrom, 2010).

The active support of the public sector to the creation and development of the academic system, and more generally of a public research system, is a key component of the knowledge governance. The public university system can be viewed as an institution that tries to reconcile the conflicting incentives necessary to fund and perform the generation of knowledge with the incentives that are necessary to secure its timely dissemination and un-limited use as an input into the generation of further technological knowledge. This result is made possible by the role of the public sector as an intermediary that collects taxes from economic agents and proves funds to the university. The university in turn provides incentives to researchers to generate and disseminate knowledge.

Together with the creation of human capital embedded with frontier competences in advanced scientific fields, the publication is the key device that makes the mechanism work. The allocation of tenures and salaries by the university is based on the proofs of the scientific capabilities of the researchers, as documented by authored publications in scientific journals that are able to screen and assess whether the contribution is actually relevant and original and such able to increase the stock of knowledge. Publications perform the twin crucial role of carriers of the proof of the scientific capabilities and vectors of the new knowledge in the dissemination process. As soon as a scientific advance is published in a scientific journal it is also made publicly available to all possible users.

On the one hand, the institutional combination of publication-cum-taxation embedded into the university makes it possible to reconcile the conflicting incentives. The prospect for the wages and eventually the tenure allocated by the university provides sufficient incentive of researchers to publish. The disclosure of the secret is compensated by the wages paid by the university. On the other hand, economic agents are ready to accept the reduction in their income engendered by the dedicated taxation necessary to support the university as long as they are compensated by the economic value that can be extracted by the free access to the new knowledge generated by the scholars organized within the academic system.

This interpretation of the university as the product of a long-term, collective process of search and implementation of an institutional design able to make possible the management of the knowledge commons has many important implications as it provides a general framework into which it is better possible to appreciate the array of specific details investigated by the recent spur of empirical work on the relations between university and industry.

The investigation into the performance of the university as a mechanism for managing knowledge commons that are able to provide a flow of useful spillovers to the rest of the system is crucial for the further implementation of its function, and possibly for guiding its maintenance. The working of the mechanism requires that a number of key assumptions be verified. The role of publications as effective carriers of scientific knowledge and vehicles for its dissemination and use for the generation of new knowledge must be confirmed and enforced. In this context , the investigation into the actual working of communication channels, including both transactions and interaction mechanisms between university and industry, is necessary to improve the actual dissemination of knowledge and its effective use by economic agents in the system.

The role of didactic activities traditionally associated with the academic institution requires further investigation. Tuition and creation of human capital are supposed to contribute to economic activity as scientific knowledge is directly embodied in human beings that are expected to have higher levels of efficiency.

The direct participation of scholars to the exploitation of new knowledge with the creation of new firms may help increase the effective use of knowledge to introduce innovations. Scientific entrepreneurship becomes a complementary communication mechanism between university and industry. The enhancement of the direct relations between scholars as individuals and universities as institutions and firms is another area of necessary investigation as it affects the fragile combination of basic incentives. Closer interactions in fact may favor the use of knowledge but limit its dissemination to third parties. For the same token, closer interactions between university and industry may help direct the scientific work towards the pursuit of specific goals, but inhibit exploration in wider and potentially more useful areas of investigation. It is clear that excess reliance of academic activity on rent-seeking funding may compromise the central role of the university in the dissemination of advanced knowledge and in the provision of knowledge spillovers to the rest of the system (Audretsch, Leyden and Link, 2012).

The academic model of knowledge governance works if the business sector within the system is able to implement dedicated strategies aimed at benefitting from the academic spillovers flowing from the public universities. The business sector should make efforts to enhance the complementarity between the internal research strategies and the academic spillovers organizing an actual division of labor between the academic sources of knowledge and its internal applications (Link and Scott, *2011)*.

When these different specifications are put in place, the academic mode of knowledge governance can be very effective as it makes it possible at the same time to incentivize the generation of knowledge, favoring the use of knowledge as an intermediary input into the recombinant generation of new knowledge and its use into the economic system as an intermediary input for the introduction of innovations. From this viewpoint, the academic mode of knowledge governance seems especially suited to exploit the special characteristics of knowledge not only as an output and an input, but more precisely its twin characteristics of a dual intermediary input, both in the generation of new knowledge and in the production of other goods (Stephan, 2011).

The papers assembled in this volume fall broadly into ten sections as shown in the table below. Also shown in the table below is a summary of the papers we have selected to characterize recent developments in the economics of science and innovation. This volume is, in a sense, a sequel to an earlier volume by Paula Stephan and David Audretsch, *The Economics of Science and Innovation*. As such, we have limited out scope of identification to scholarship in print over the past decade.

Sections	**Summary**
Models of Science and Innovation	Innovation and the process bringing innovation about are built on scientific research (Fleming and Sorenson, 2004). This research, which leads to innovation, has classical origins (Antonelli, 2009) and is often characterized pedagogically by a linear model (Godin, 2012).
The Evolving Role of Knowledge	Knowledge can be codified and tacit (Cowan, David, and Foray, 2000), and both forms of knowledge are important for economic growth (Medcalfe, 2002). Still, the economics of knowledge is best understood through a systematic framework that emphasizes both its direct and indirect impacts on systems (Antonelli, 2007).
Markets for Technology and Innovation	With their imperfections, markets for knowledge—*per se* knowledge or knowledge embodied in technologies—are continuing to develop (Arora, Fosfuri, and Gambardella, 2001). This is especially true in both the pharmaceutical industry (Nesta and Saviotti, 2005) and the biotechnology industry (Zucker and Darby, 2001; Gittelman and Kogut, 2003). However, an economic case can be made, especially with regard to the software industry, for technologies to be available through open sources (Lerner and Triole, 2002).
Markets for Scientists	In contrast to developing markets for knowledge, there are well developed markets for scientists, from which knowledge emanates and to which knowledge flows (Dietz, Chompalov, Bozeman, Lane, and Park, 2000; Gaughan and Robin, 2004; Jones, 2009). But, as functioning as these markets are, the role of government to subsidize both the supply and the demand remains an issue for discussion (Romer, 2001).
R&D Investments in Innovation	Fundamental to the creation, diffusion, and adoption of innovations are investments in R&D. Although often cyclical (Barlevy, 2007), the spillover benefits of R&D are often as important, from an economic perspective, as are the own effects (Cassiman and Veugelers, 2002).

Innovation and Knowledge Networks	The effectiveness of R&D, knowledge flows, and technological growth is influenced by property rights, knowledge networks, and the maturity of innovation systems (Kogut, 2000; Antonelli, 2008).
Institutions to Support Innovation	A number of institutions support the innovation process. These include incubators (Hackett and Dilts, 2004), university research parks (Link and Scott, 2007), and proof of concept centers (Gulbranson and Audretsch, 2008).
University Support of Science and Innovation	Universities serve as an important dimension of the innovation process. Universities are often the source of innovation as reflected through the patenting behavior of faculty (Jensen and Thursby, 2001; Allen, Link, and rosenbaum, 2007; Azoulay, Ding, and Stuart, 2007; Stephan, Gurmu, Sumell, and Black, 2007; Lach and Schankerman, 2008).
Public Support of Scientific Research and Innovation	The private sector underinvests in R&D due in part to market failures associated with the inability of firms to appropriate fully the benefits from their R&D investments. This argument opens the door for public support of research and innovation (Link and Scott, 2001; Fleming and Sorenson, 2001; Cohen, Nelson, and Walsh, 2002; Link and Scott, 2009).
Public Policies toward Science and Innovation	In industrialized nations there are infrastructures and focuses policies to aid in the support of innovation, such as a national laboratory system (Jaffe and Lerner, 2001) and targeted public policies (Mohnen and Röller, 2005; Jaffe, Newell, and Stavins, 2005).

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